

National Aeronautics and  
Space Administration

Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California

# AIRS Project Overview

March 27, 2007

Thomas S. Pagano  
AIRS Project Manager  
Jet Propulsion Laboratory  
California Institute of Technology



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# Agenda

- AIRS on Aqua
- AIRS Products
- AIRS Accomplishments
- AIRS Accuracy and Stability
- Questions for Team
- Future Direction



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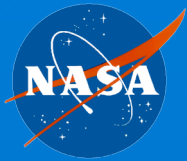
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# AQUA WAS LAUNCHED ON MAY 5, 2002

## ~5 Year Anniversary

- Delta 2 Launch Vehicle
- 6 Strap On Boosters
- Extended Fairing
- 2:55 AM
- Vandenburg Air Force Base, California
- 705.3 km Orbit
- Polar Sun Synchronous
- 1:30 PM Equatorial Crossing
- Ascending Daytime

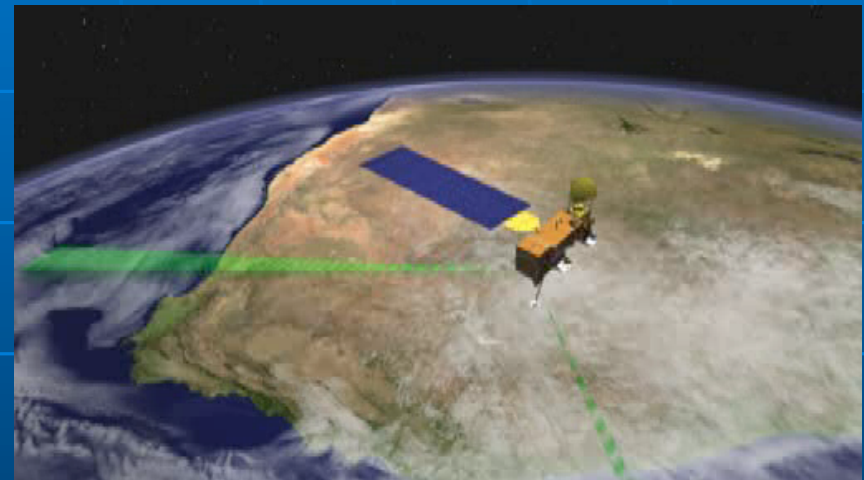
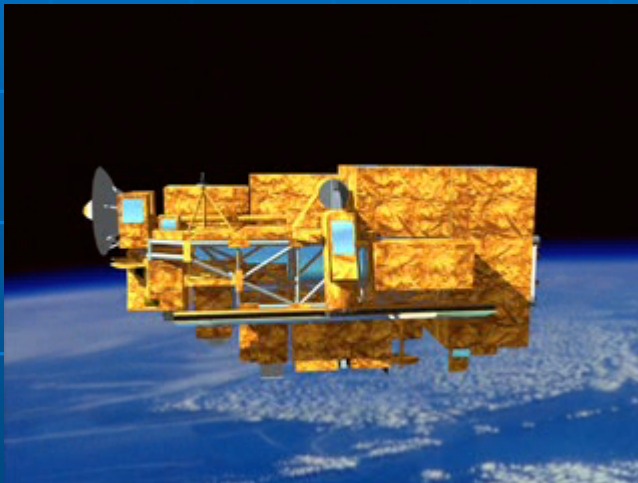




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# 5 Year Anniversary of the Launch of the Aqua Spacecraft



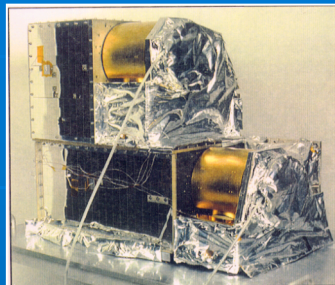




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## AIRS/AMSU/HSB on Aqua

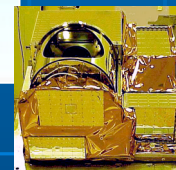
- Aqua Spacecraft: At least 8 more years expected.
- AIRS Continues Normal Operations
- AMSU in Normal Operations
- HSB Non-Operational since 2/2003



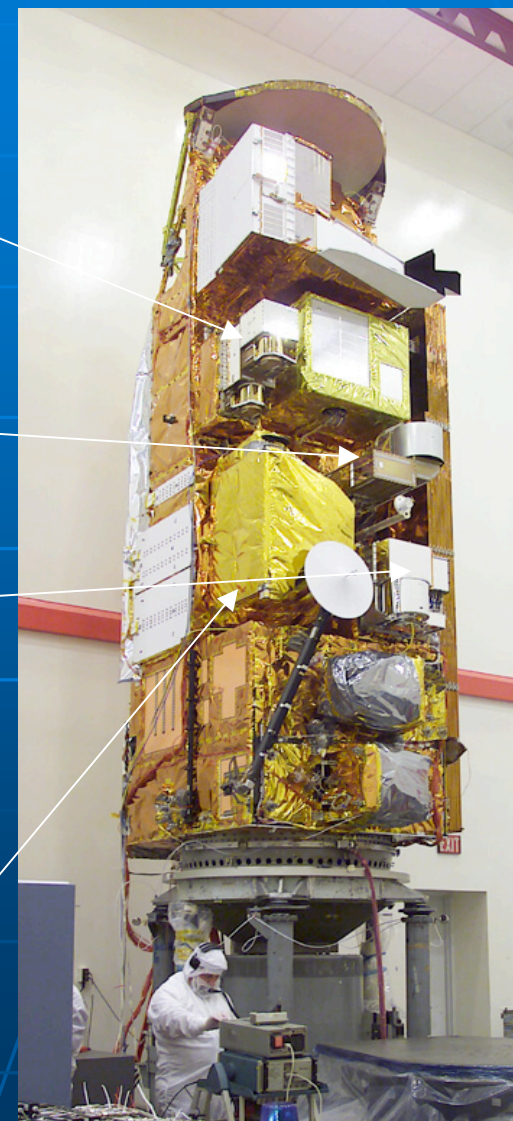
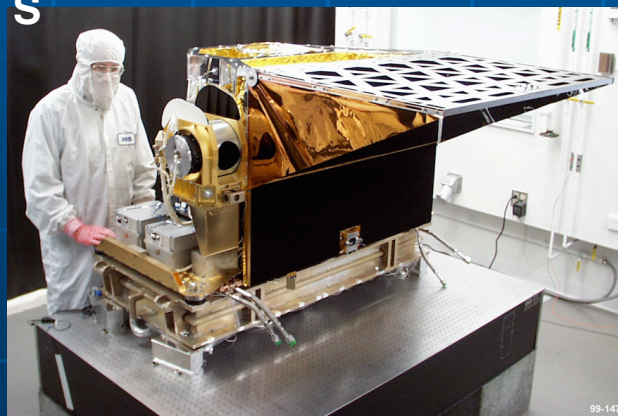
AMSU



HSB



AIRS

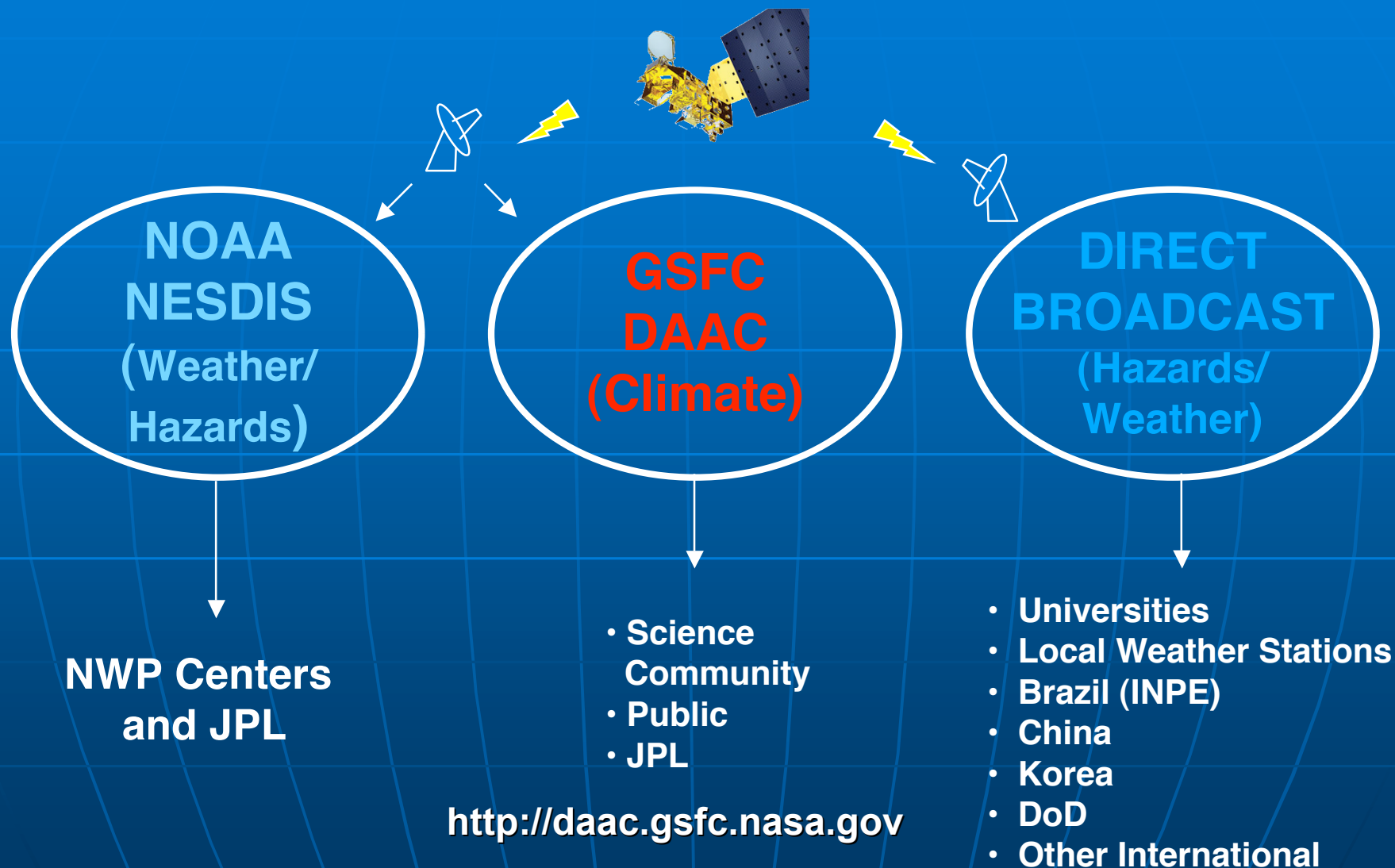


THE AQUA SPACECRAFT



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## AIRS/AMSU DATA DISTRIBUTION CENTERS



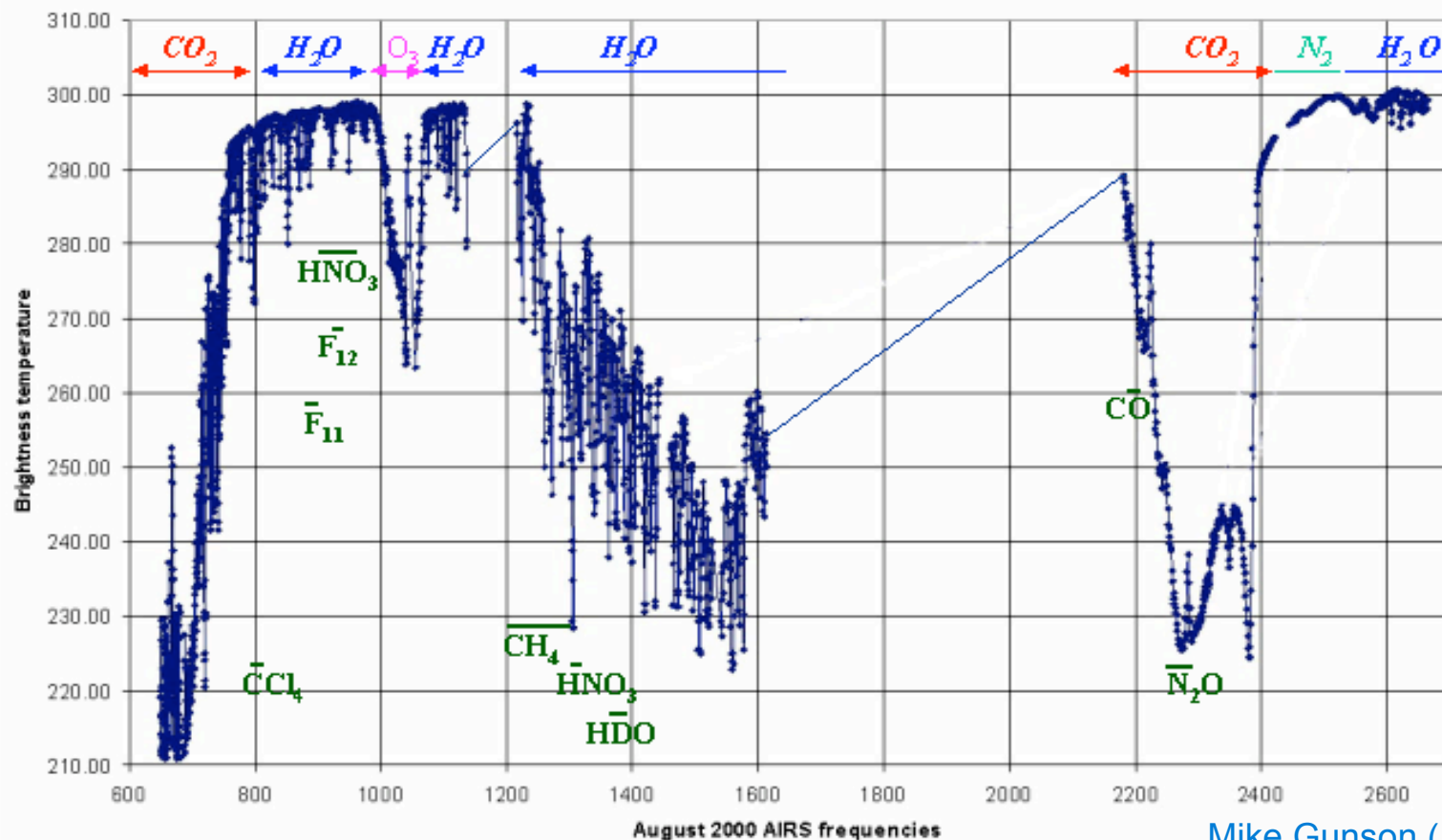


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# AIRS Acquired Hyperspectral IR Spectrum of the Earth Atmosphere. Globally. Daily.

AIRS Channels for Tropical Atmosphere with  $T_{\text{surf}} = 301\text{K}$

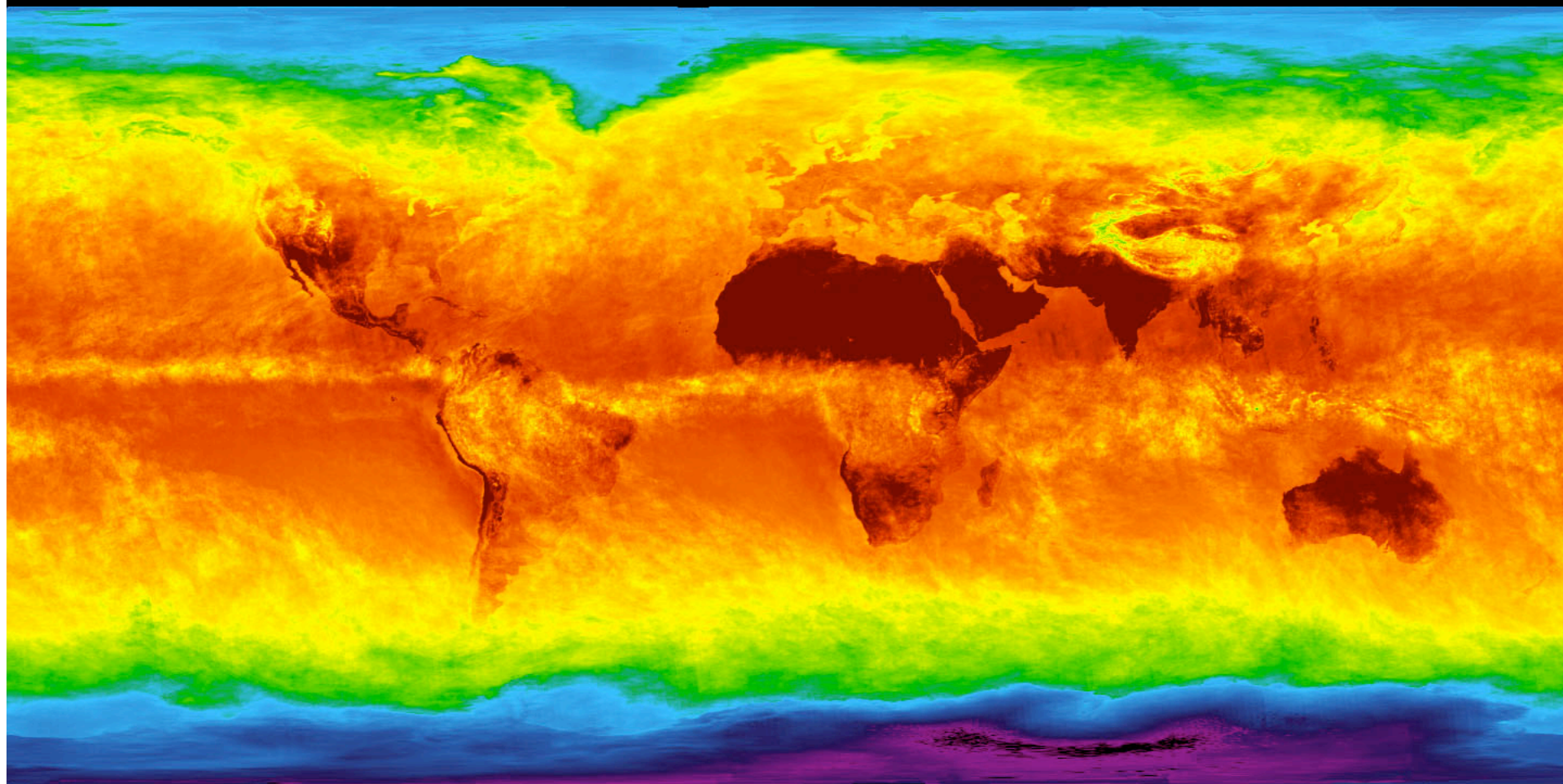
Full Spectrum



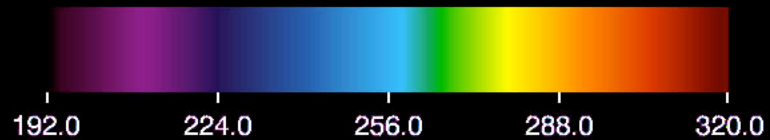
Mike Gunson (JPL)



AIRS MONTHLY AVERAGE UPWELLING RADIANCE FOR  
APRIL, 2003. 2616 cm<sup>-1</sup>



Degrees Kelvin



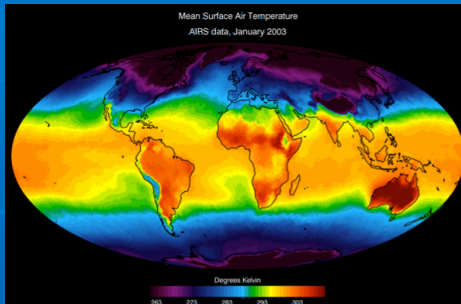
*C. Thompson*



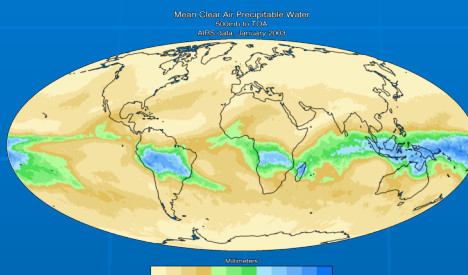
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# AIRS Products Support Climate Studies

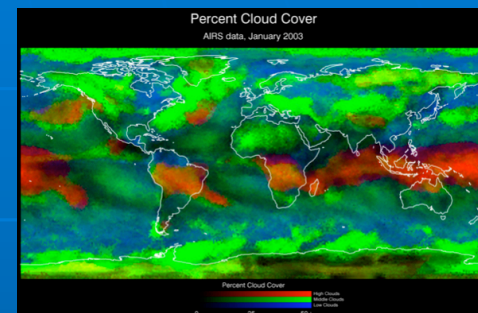
## Atmospheric Temperature



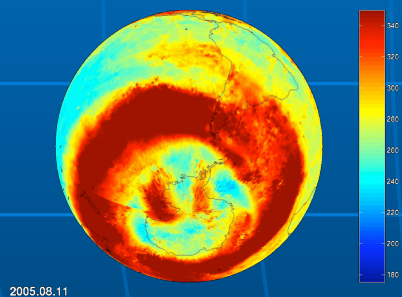
## Atmospheric Water Vapor



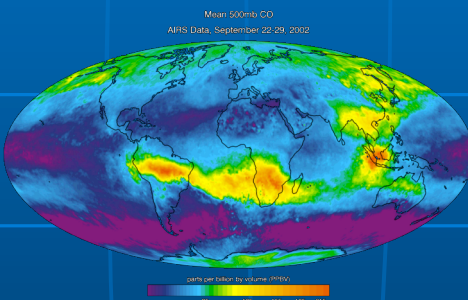
## Cloud Properties



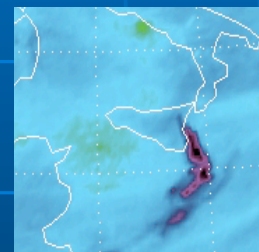
## Ozone



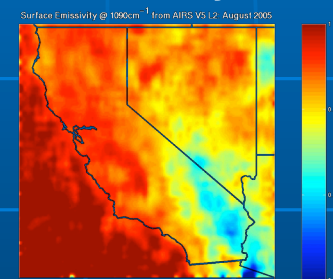
## CO



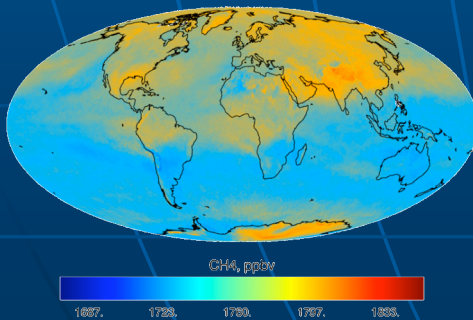
## SO2



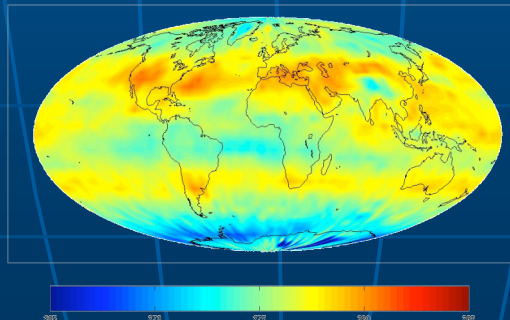
## Emissivity



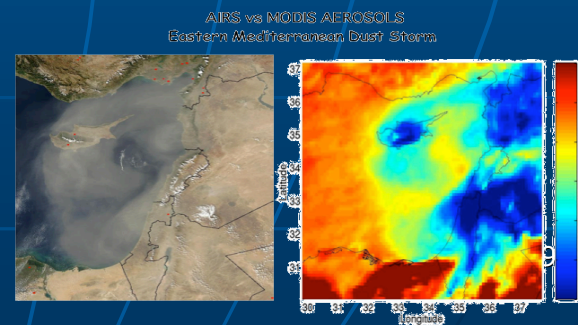
## Methane

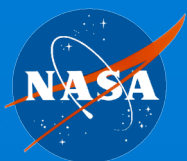


## CO2



## Dust





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## AIRS/AMSU/HSB V5 Standard Products

Product	RMS Requirement	Current Estimate	Validation Status
<b>Radiance Products (Level 1B)</b>			
AIRS IR Radiance	3%*	<0.2%	Val3
AIRS VIS/NIR Radiance	20%	10-15%	Val3
AMSU Radiance	0.25-1.2 K	1-2 K	Val1
HSB Radiance	1.0-1.2 K	N/A	Val1
<b>Standard Geophy Products (Level 2,3)</b>			
Cloud Cleared IR Radiance	1.0 K	<1.0 K	Val1
Sea Surface Temperature	0.5 K	1.0K	Val1
Land Surface Temperature	1.0 K	N/A	Beta
Temperature Profile	1 K / km	1K / km	Val3
Water Vapor Profile	15% / 2 km	15% / 2km	Val3
Total Precipitable Water	5%	5%	Val3
Fractional Cloud Cover	5%	TBD	TBD
Cloud Top Height	0.5 km	TBD	TBD
Cloud Top Temperature	1.0 K	TBD	TBD
Total Ozone Column	-	5%	Val3
<i>Ozone Profile (250 mb – 70 mb)</i>	-	20%	Val2
<i>Carbon Monoxide</i>	-	15%	Val2
<i>Methane</i>	-	2%	Val2





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# AIRS Version 5.0 Enhancements

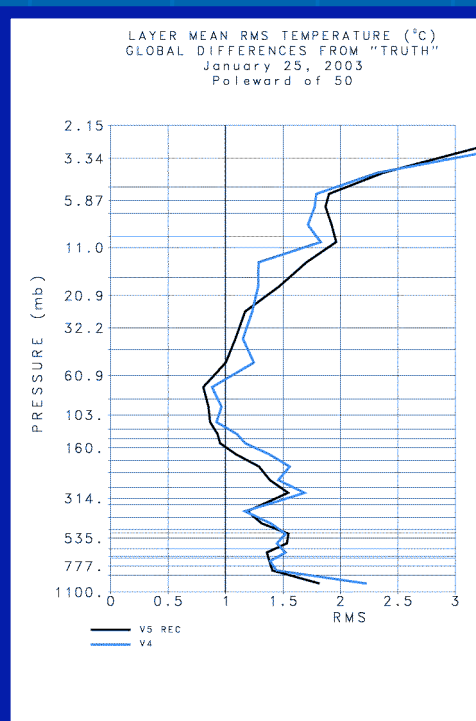
## V5 Performance Enhancements

- *Lower Errors Near Surface*
- *Reduced Bias in Mid Trop*
- *Higher Yield in Troposphere*
- *Improved Error Estimates*

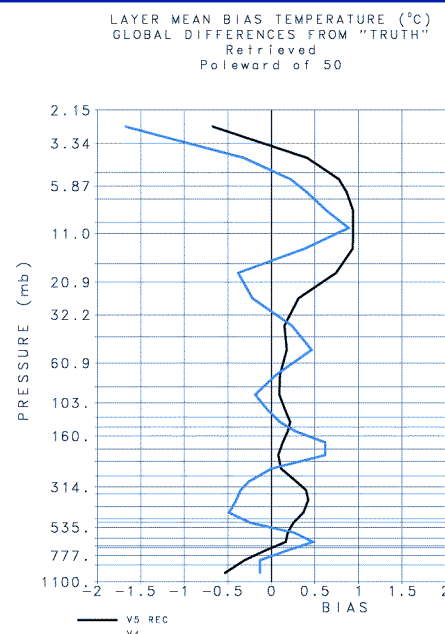
## V5 Additional Enhancements

- *CO, O<sub>3</sub>, and CH<sub>4</sub> Profiles*
- *Aerosol and SO<sub>2</sub> Flags*
- *All Products Near Real Time*
- *First Post-Launch L2 ATBD*
- *Improved Testing*

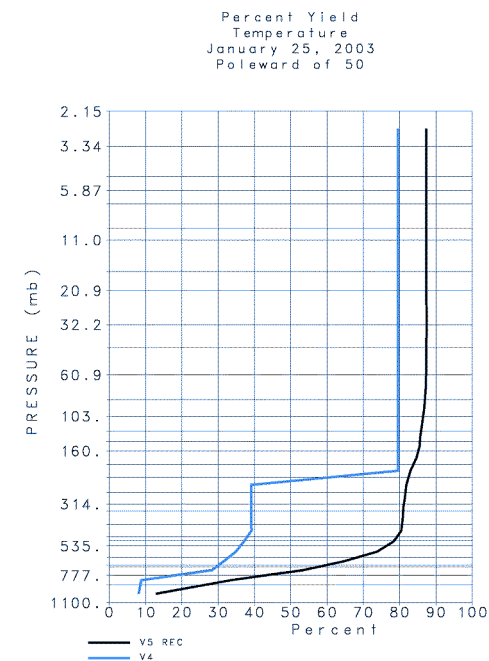
T<sub>RMS</sub>



T<sub>BIAS</sub>

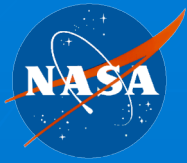


Yield



Susskind GSFC





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## AIRS Improves Weather Forecasting and Climate Modeling

- **Improved weather prediction**

- 11 Hours on the 6 Day Forecast (6 hours Operational Today)
- GCM Process Validation (H<sub>2</sub>O, Clouds, Temperature)
- Retrieve surface spectral emissivity for data assimilation

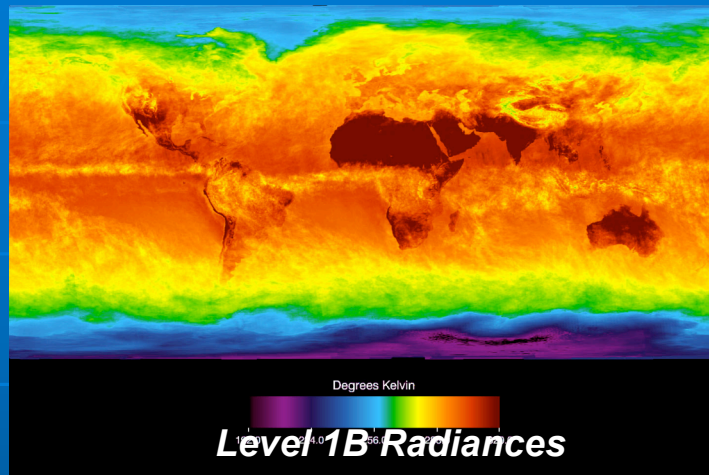
- **Improved climate prediction**

- Measure the primary Earth Science gases:  
H<sub>2</sub>O, CO<sub>2</sub>, CH<sub>4</sub>, CO, O<sub>3</sub>
- Improved Global Transport Studies
- Determine role of water vapor and clouds on radiation balance
- Data used to validate and provide parameterization for climate models



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# AIRS is Improving Global and Regional Weather Forecasting



Level 1B Radiances



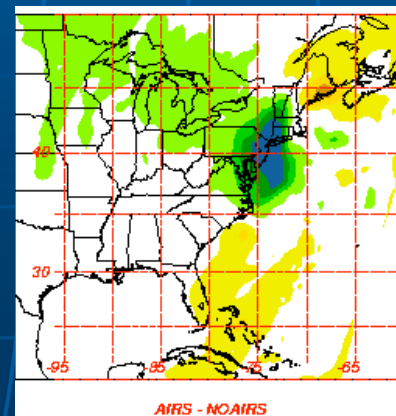
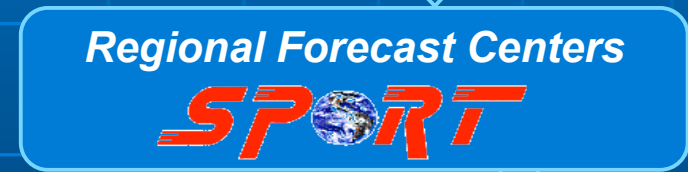
3D Temperature  
and Water Vapor Profiles

Near Real Time  
Assimilation



NCEP, ECMWF, and UKMet  
Operational Forecasts

6 Hrs on 6 Day Improvement on  
Operational NCEP Forecast



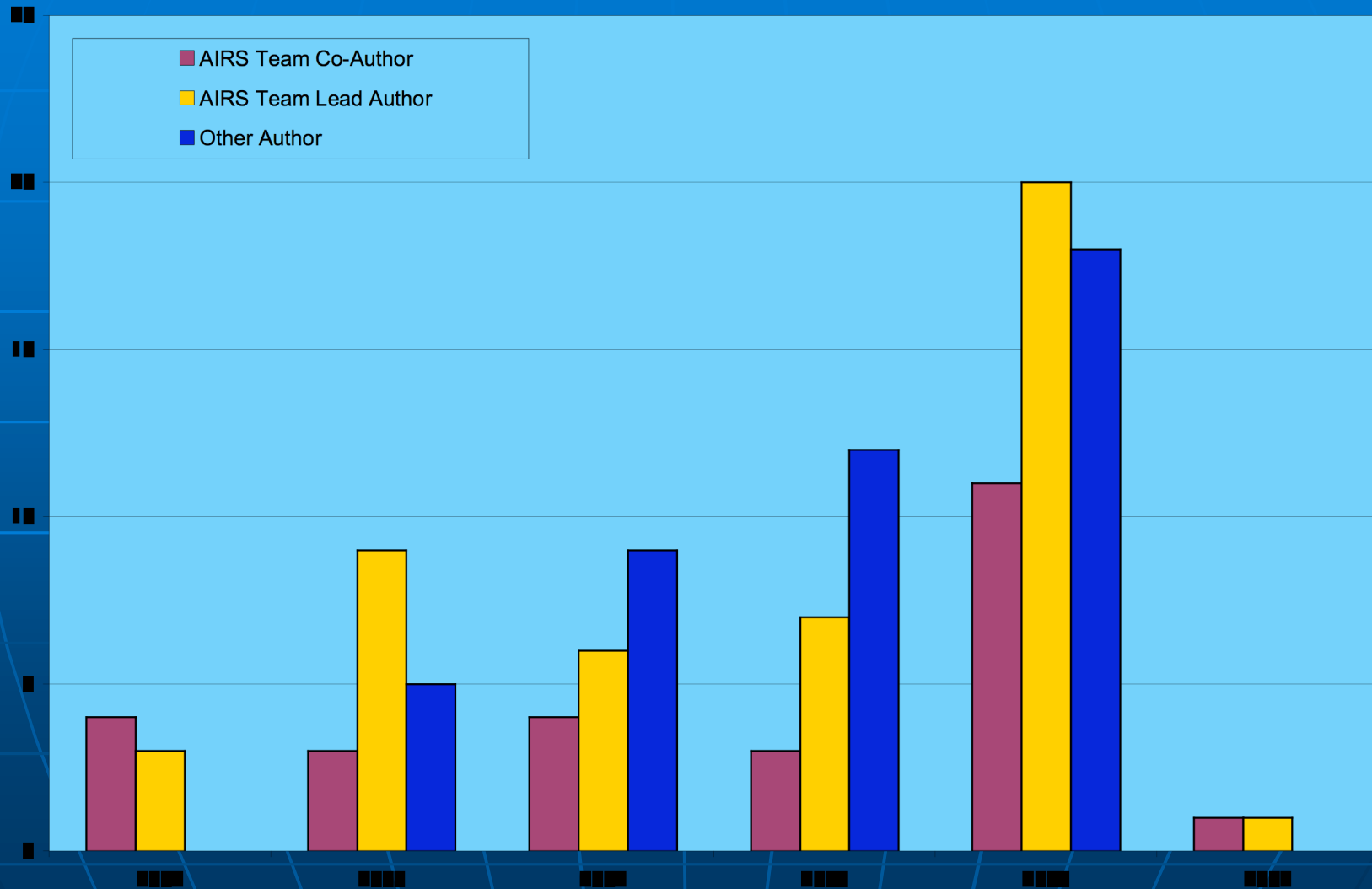
Over 4 hPa  
Improvement in  
Regional Model  
Forecast

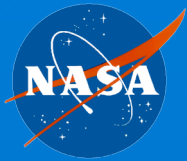


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## AIRS Peer-Reviewed Science Publications

Publications Available as of 01/23/07; 133 Total



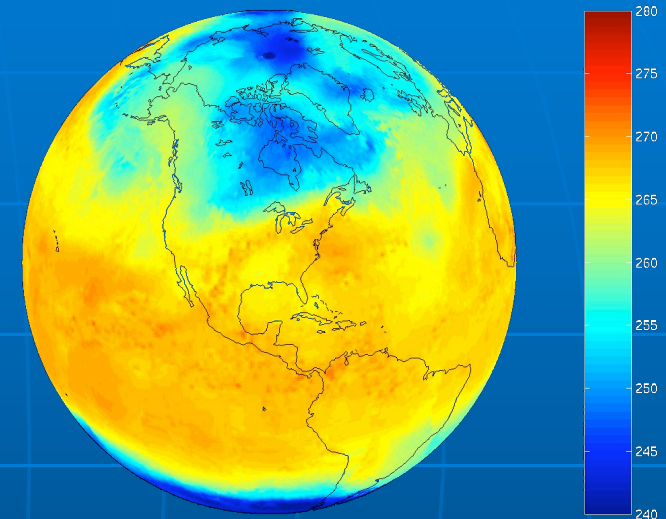


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# AIRS Improving Weather Forecasts

- AIRS Data Assimilated in Operational Forecast
  - AIRS data are being assimilated by NOAA's National Centers for Environmental Prediction (NCEP) and by the European Centre for Medium-Range Weather Forecasts (ECMWF) and United Kingdom Met Office (UK Met Office).
- AIRS Improves Forecast by 6 hours in 6 days
  - Assimilation of thinned (<1%) AIRS spectra improve
  - Le Marshall *et al.* 2006 and McNally *et al.* 2006

500 mb Temperature (K)



2005.08.13

- AIRS Improve Tropical Cyclone Position and Intensity Prediction
  - Assimilation of AIRS retrieved temperature profiles into the Finite Volume Data Assimilation System (FVDAS) improves the prediction of the intensity and location of cyclones in the Southern Hemisphere (Atlas 2005).
- AIRS Studies Hurricane Formation
  - Assimilation of the AIRS Level 2 products into the Fifth Generation NCAR/Penn State Mesoscale Model (MM5) shows that the Saharan Air Layer may have delayed the formation of Hurricane Isabel and inhibited the development of another tropical disturbance to the east (Wu *et al.* 2006).



## AIRS Improving and Validating Climate Models

### ■ AIRS Validates Moisture in Weather Models

- AIRS/AMSU water vapor observations reveal tropospheric moisture perturbations that are much larger than those depicted in previous NCAR/NCEP reanalysis and ECMWF analysis data sets, both of which have been widely used as observations to validate models. This suggests that the impact of convection-induced downdrafts on the atmospheric boundary layer is significantly underestimated in both ECMWF and NCEP reanalysis data sets (Fu et al. 2006).

### ■ AIRS Validates Moisture in Climate Models

- Comparison of moisture fields of six major climate models with AIRS measurements establish that these models simulate conditions that are drier than the observations by 10%-25% in the tropics below 800 mb but more moist than the observations by 25%-100% between 300-600 mb, especially in the extratropics. This affects the model-estimated range of climate warming anticipated over the current century (Pierce et al. 2006).

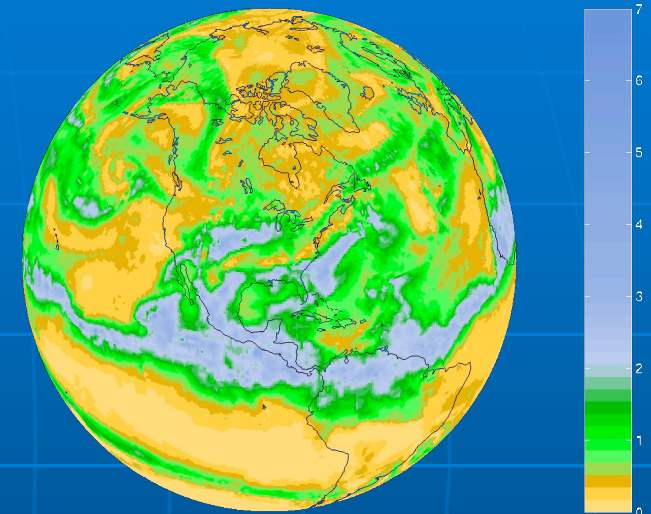
### ■ AIRS Finds Correlation of SST and Greenhouse Effect

- AIRS/AMSU data have led to the determination that the greenhouse effect appears to increase with SST and that although the water vapor feedback is positive, it is not as positive as a constant relative humidity profile would produce (Gettelman et al. 2006a).

### ■ AIRS Team examine Climate Feedbacks

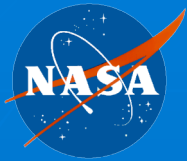
- CERES and AIRS observations were used to test, for the first time, climate model representations of critical climate feedbacks in the tropical upper troposphere and the coupling of the tropical upper troposphere to the surface (Gettelman et al. 2007)

*500 mb Water Vapor (g/kg dry air)*



2005.08.11

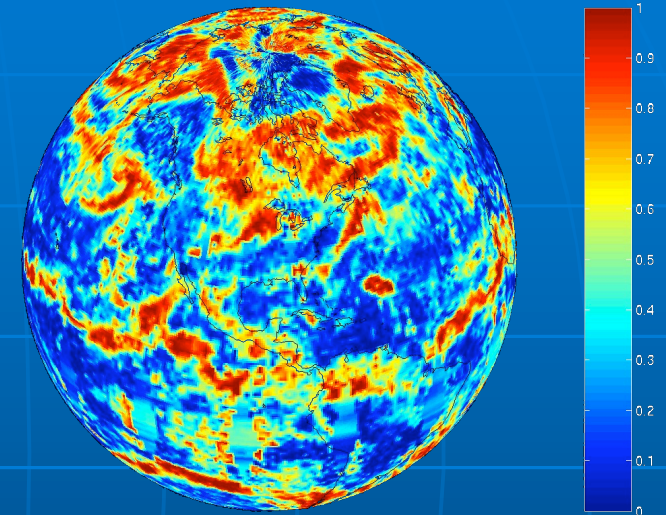




## AIRS Climate Model Support (continued)

- AIRS shows errors in H<sub>2</sub>O model during MJO
  - AIRS/AMSU data have led to the discovery of significant differences in the lower-troposphere moisture and temperature fields during the spatial-temporal evolution of the Madden-Julian Oscillation (MJO). (Tian et al. 2006).
- AIRS identifies transport processes
  - AIRS/AMSU data have led to the finding that the transient convective events in the Asian summer monsoon anticyclone are associated with the vertical transport of low ozone and high water vapor into the upper troposphere/lower stratosphere (UTLS) region (Randel and Park 2006).
- AIRS Shows Phasing of Thunderstorms and SST
  - AIRS/AMSU data have led to the finding that the onset of the severe thunderstorm activity lags the top-of-the atmosphere (TOA) incident solar flux by about two months, while the sea surface temperature lags by about three months (Aumann et al. 2007).
- AIRS Retrieves Cirrus
  - AIRS data enable the accurate retrieval of opacity due to small-particle-dominated cirrus clouds over the globe (Kahn et al. 2005). The AIRS radiance product spectral resolution allows detection of minima in the atmospheric window brightness temperatures between 800 cm<sup>-1</sup> and 850 cm<sup>-1</sup> that modeling show to result from ice particles smaller than 3 μm.

*Cloud Fraction*



2005.08.11



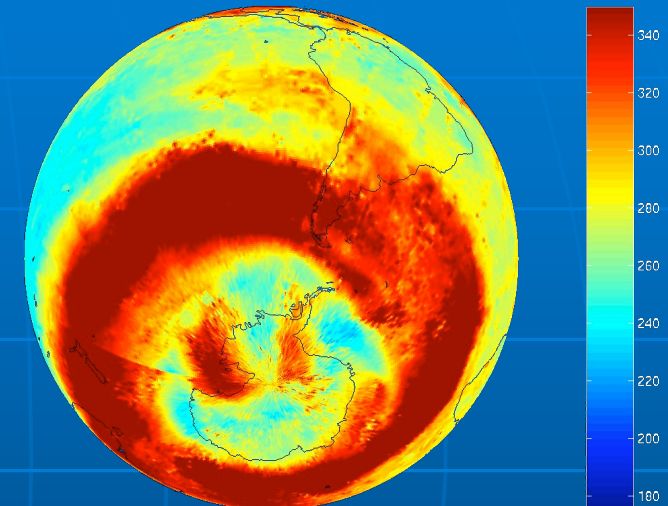
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# AIRS 3D Ozone Profile Allows Viewing Stratospheric Tropospheric Exchange as well as global transport

## ■ Ozone

- AIRS/AMSU data map the global distribution of O<sub>3</sub> for all seasons of the year.
- AIRS average total column O<sub>3</sub> matches to within 5% of that observed by Total Ozone Mapping Spectrometer (TOMS)
- AIRS observes Stratospheric Tropospheric Exchange (Pan, 2006)
- AIRS Observes Global Transport

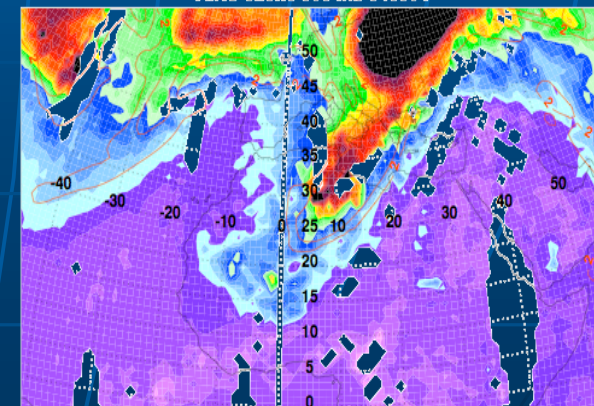
*Total Column Ozone (DU)*



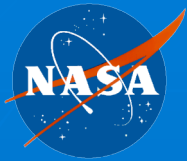
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*AIRS Ozone Profile*

AIRS ozone 300 mb 040304







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## AIRS Carbon Monoxide and Methane New in Version 5.0

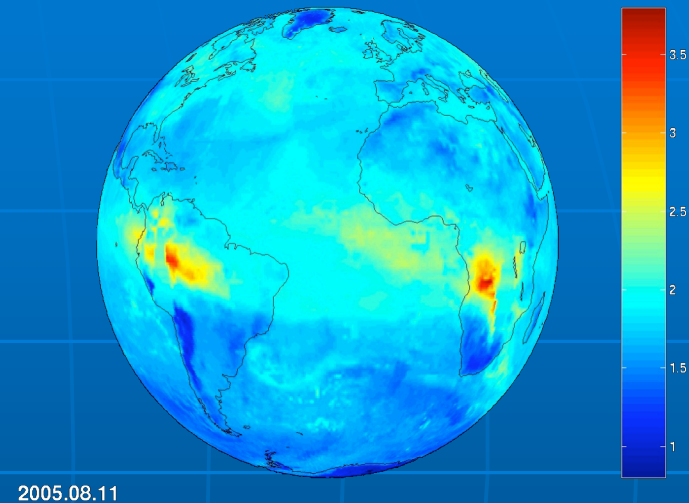
### ■ CO

- AIRS/AMSU data have provided the most detailed, daily global observation of transport of mid-tropospheric CO from biomass burning emissions (McMillan et al. 2005).
- AIRS CO retrievals have been found to validate the plume rise mechanism in simulations of the transport of CO in the mid-troposphere (Freitas et al. 2006).
- AIRS Observes Natural and Anthropogenic sources of CO<sub>2</sub> (McMillan 2006)

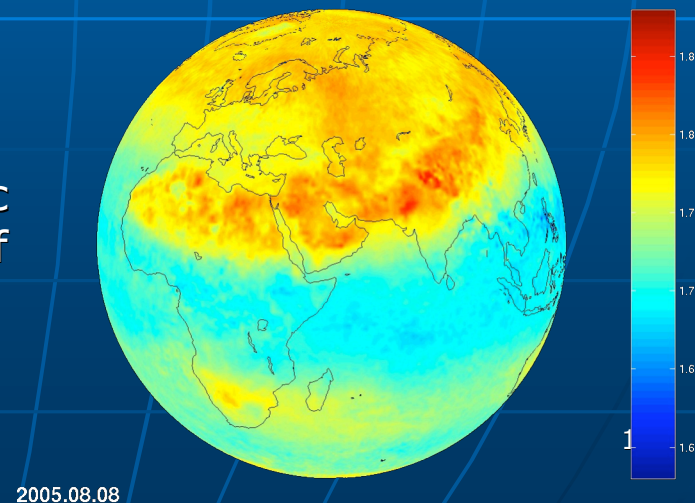
### ■ CH<sub>4</sub>

- AIRS/AMSU data have provided the first observed seasonal variation of atmospheric CH<sub>4</sub> over the permafrost sub-arctic zone of west Siberia, and identification of significant anthropogenic sources in the winter (Yu et al. 2005 and Griбанov et al. 2007).

*Carbon Monoxide (DU)*



*CH<sub>4</sub> Volume Mixing Ratio, 210 mb*





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# AIRS SO<sub>2</sub> and Aerosols Now Flag in Version 5 L1B

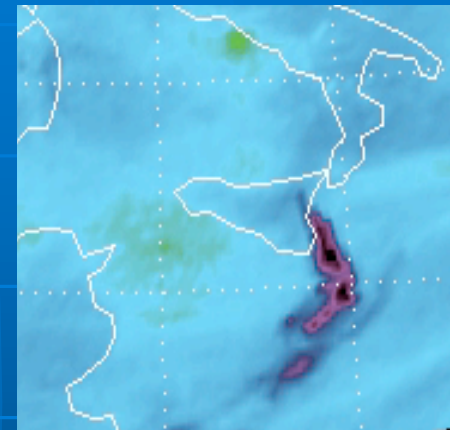
## ■ SO<sub>2</sub>

- Inclusion of AIRS SO<sub>2</sub> information has been found to improve measurements of volcanic SO<sub>2</sub> and ash loading in the troposphere, thereby improving our understanding of volcanic cloud composition, structure and evolution (Wright et al. 2005)
- AIRS Data are used Operationally by the Volcanic Ash Advisory Center in Washington DC (through NOAA)

## ■ Dust and Aerosols

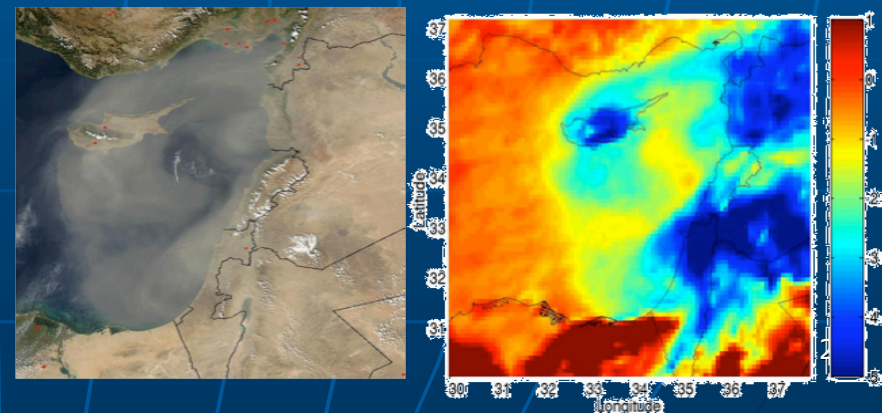
- AIRS Measures IR Optical Thickness, Particle Size and Spectral Signature (Machado 2006)

*AIRS SO<sub>2</sub> Signature*



*Dust*

AIRS vs MODIS AEROSOLS  
Eastern Mediterranean Dust Storm



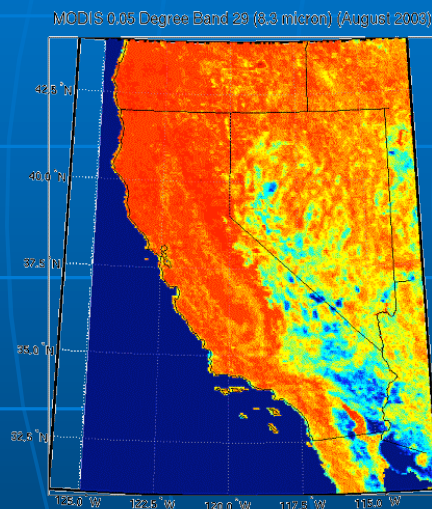


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# AIRS V5 Emissivity Compares Well with ASTER and MODIS

One Month August  
August 2003  
Cloud-Free Scenes

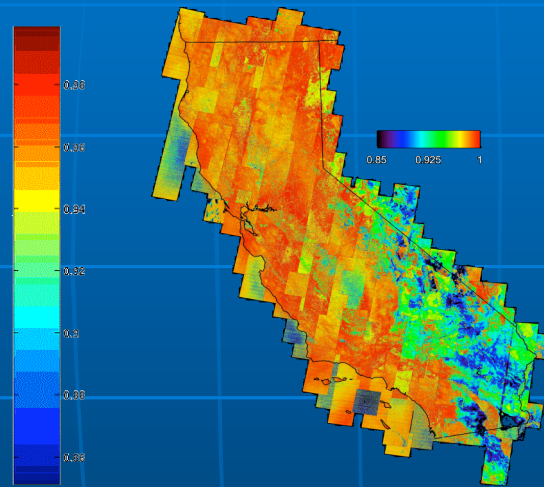
**MODIS**



**5x5 km**  
 **$\nu = 1205 \text{ cm}^{-1}$**

June-July-August  
2000-2005  
Cloud-Free Scenes

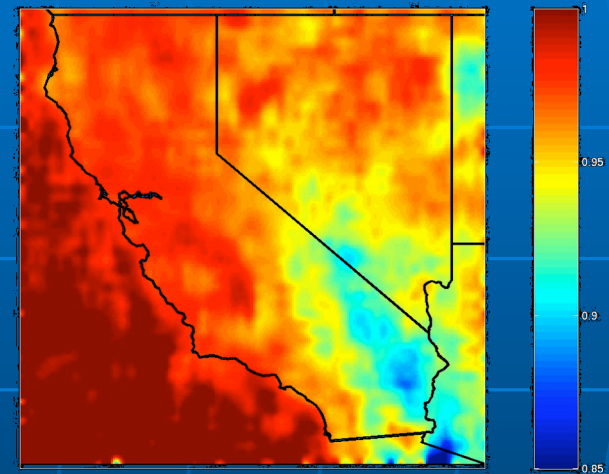
**ASTER**



**100x100 m**  
 **$\nu = 1204 \text{ cm}^{-1}$**

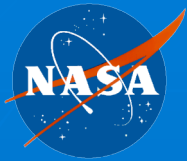
One Month  
August 2005  
Cloud-cleared

**AIRS**



**50x50 km**  
 **$\nu = 1095 \text{ cm}^{-1}$**





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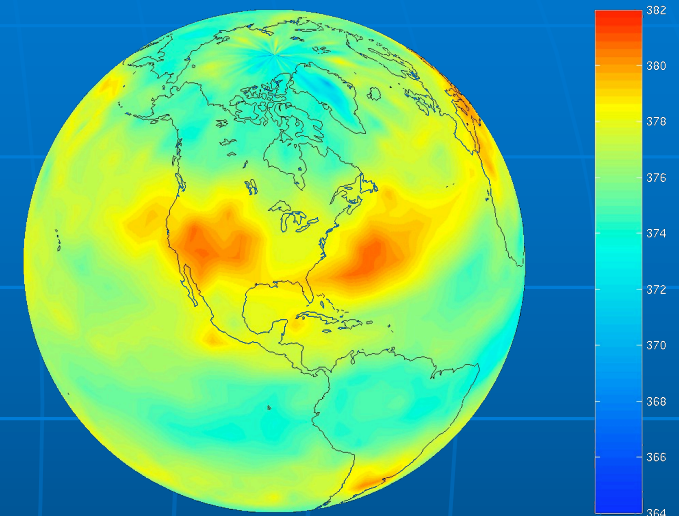
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## Carbon Dioxide Mid Troposphere Research Products Are Under Development

- AIRS Retrieving CO<sub>2</sub> by direct observation. Validated using aircraft data (Chahine 2005, et. al.)
- AIRS/AMSU have provided the first maps of CO<sub>2</sub> in the tropical cloud-free upper troposphere (Chevallier et al. 2005) and research has shown that direct retrievals are capable of providing detailed daily global maps of the mid-tropospheric (500 mb) CO<sub>2</sub> distribution.
- Significant differences have been found between simulated and AIRS/AMSU-derived CO<sub>2</sub> abundance outside of the tropics, raising questions about the lower-to-upper troposphere transport pathways in current numerical models (Tiwari et al. 2006).
- AIRS/AMSU CO<sub>2</sub> data have been assimilated as a tracer in a full four-dimensional-variational (4D-Var) ECMWF transport model (Engelen and McNally 2005), treating CO<sub>2</sub> on the same footing as water vapor, cloud variables, ozone, etc.

*Carbon Dioxide (ppbv)*

500 mb CO<sub>2</sub>, July 2003, V5





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## AIRS Highlights at AMS

- Berrien Moore Co-Chair, NRC Decadal Survey Committee, at Decadal Survey Town Hall Meeting
  - AIRS is a good example of how NASA and NOAA work together to improve weather forecasts
- Mike Freilich, NASA Earth Science Director at NASA Town Hall Meeting
  - AIRS has demonstrated “significant” positive forecast impact
- Louis Uccellini, Director NCEP
  - AIRS has had the most impact of any instrument assimilated to date and is highest priority for assimilation after installation of new computer systems
- Tony Hollingsworth, ECMWF
  - Showed radiation fields improvement with assimilation of AIRS CO2 channels
- Numerous posters and papers using AIRS data for climate and weather forecast impact and validation
- Exhibits by NASA and BAE Systems



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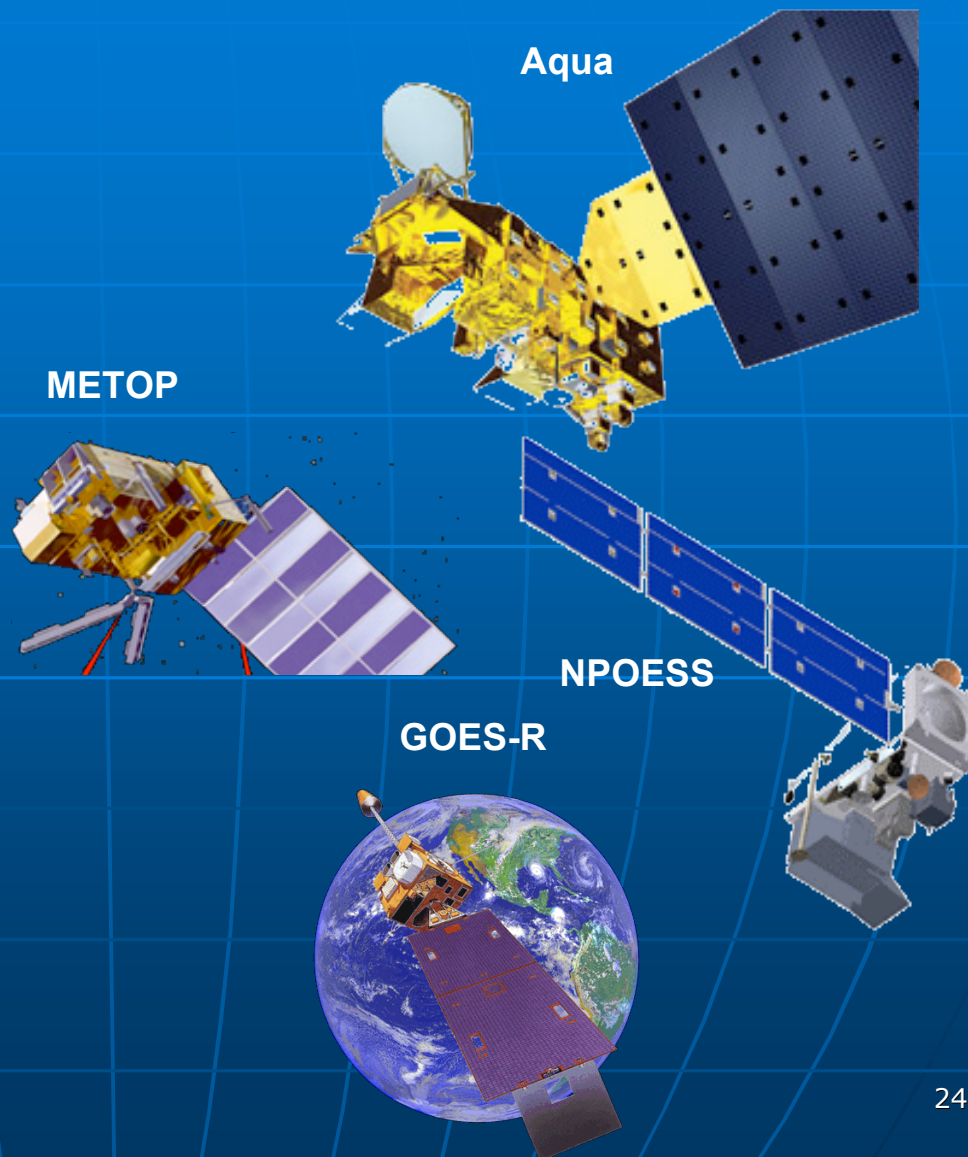
# AIRS Experiment Paving the Way for Future Planned Sounders

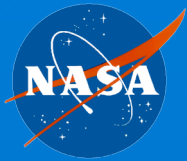
## ■ Current IR Sounder

- AIRS on Aqua
  - 2002 Launch
  - LEO
  - 3.7-15.4 mm
  - 13.5 km IFOV

## ■ Planned IR Sounders

- IASI on METOP
  - Launched October, 2006
  - LEO
  - 3.6-15.4 mm
  - 12 km IFOV (25 km GSD)
- CrIS on NPP/NPOESS
  - 2010 1<sup>st</sup> Launch
  - LEO
  - 3.9-15.4 mm
  - 14 km IFOV
- HES on GOES-R
  - TBD Launch
  - GEO
  - 4.4 – 15.4 mm
  - 4 km IFOV

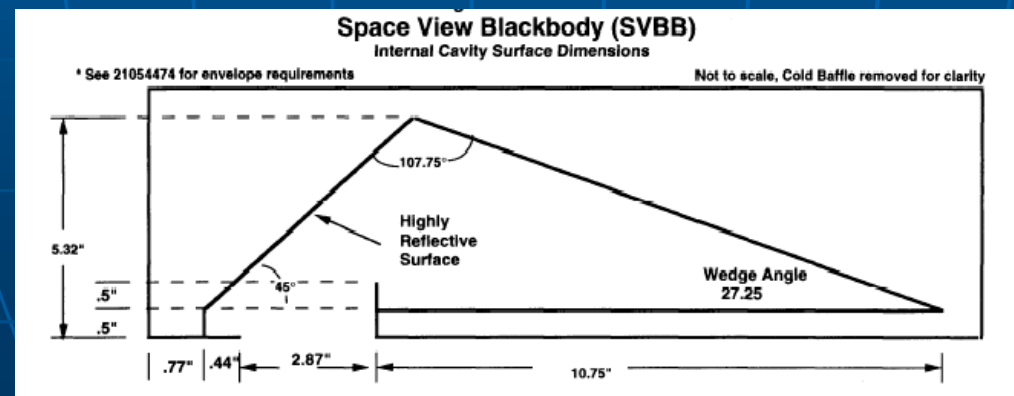
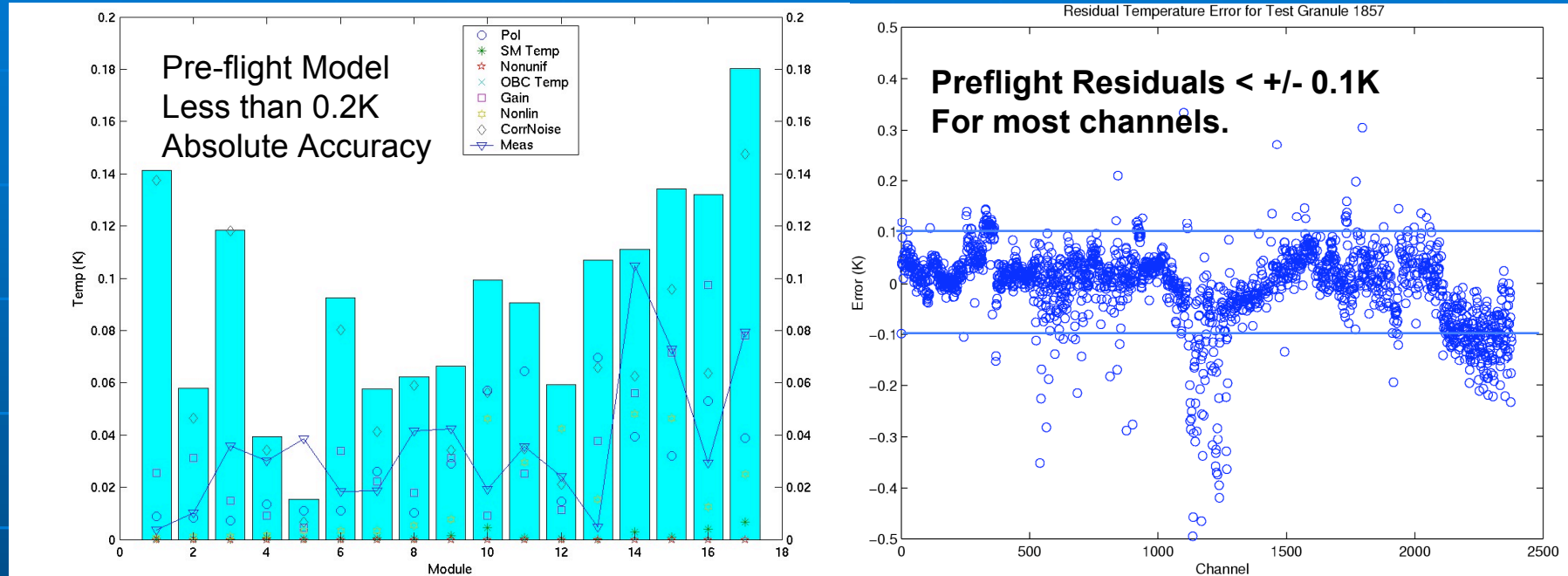




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# Preflight Accuracy Prediction and Measurement: 0.1K – 0.2K

## AIRS Well Characterized Pre-launch







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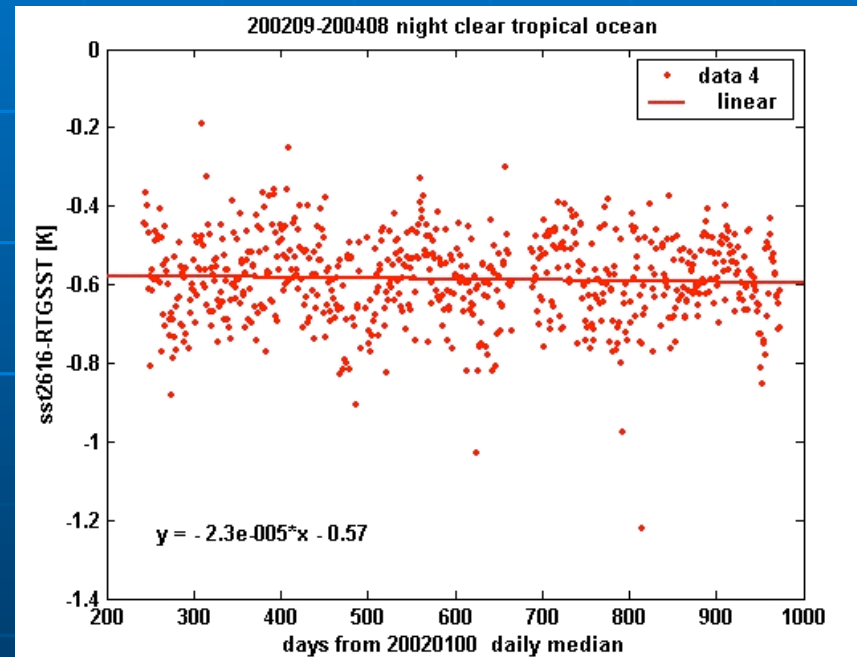
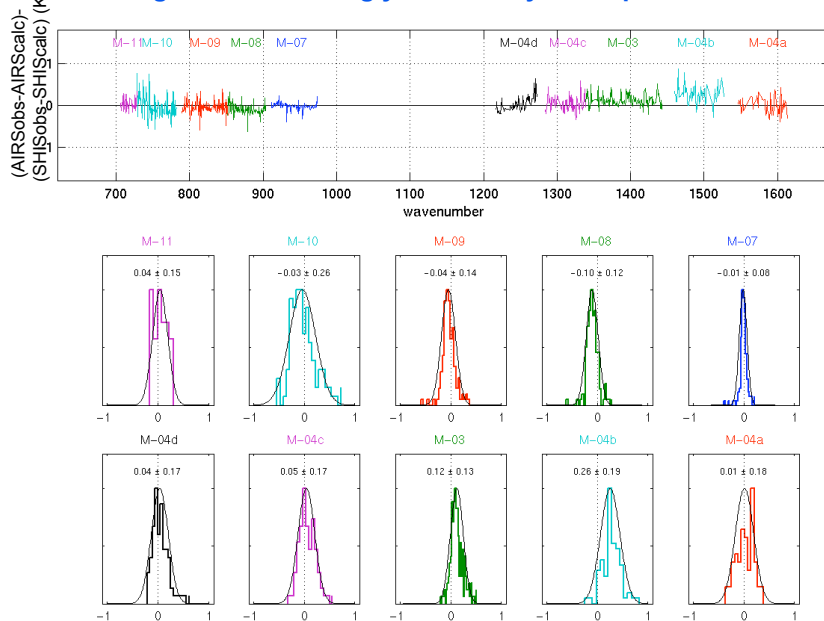
# AIRS Accuracy and Stability Make it a “Climate Quality Sensor”

## AIRS Accuracy and Stability Verified In Orbit using Ground Truth

Scanning HIS Validates Rad Accy  
to 0.2K – H. Revercomb (UW)

AIRS Radiometric Performance: Stable  
to <8mK/Y – H. Aumann (JPL)

Final “Comparison 2” (21 November 2002)  
Excluding channels strongly affected by atmosphere above ER2





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# ARIES Concept is Higher Spatial and Spectral Resolution AIRS

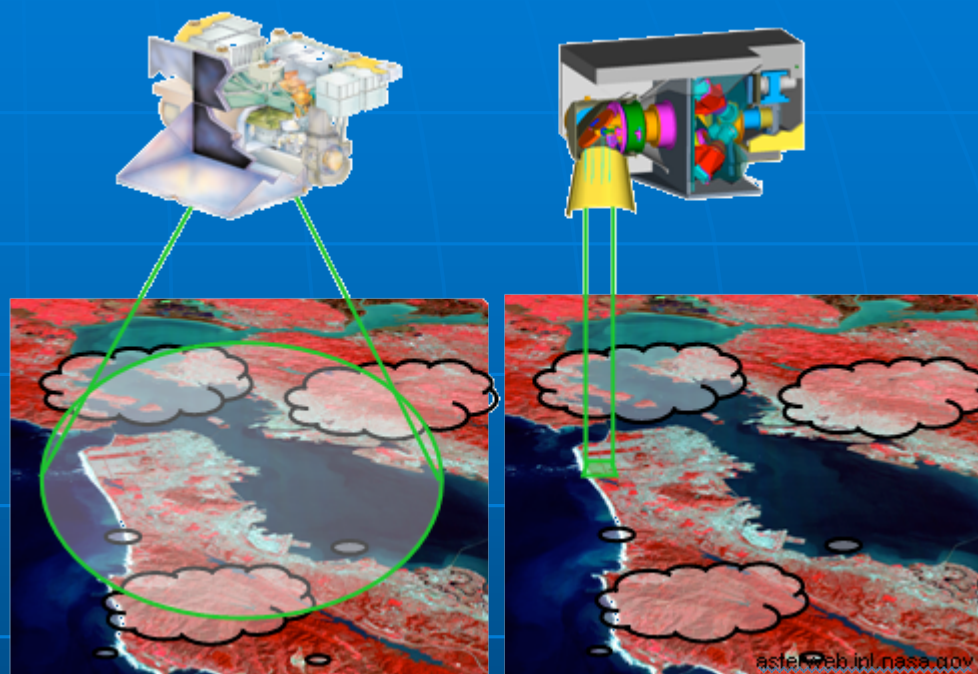
## *Advanced Remote-sensing Infrared Emission Spectrometer ARIES*

### Characteristics:

- **1x1 km Horizontal Resolution**
- **3.0 – 15.4  $\mu\text{m}$**
- Hyperspectral: Over 3000 Channels
- Global Daily Coverage ( $\pm 55^\circ$  Swath)

### Features

- Higher Spectral Resolution
  - **Resolves Boundary Layer**
    - Improves Vertical Resolution
- Higher Spatial Resolution
  - Improves Cloud Clearing
  - Gives Surface Spectral Emissivity
  - Allows 3D Transport Studies



Band	Spectral Range	$\Delta\nu$	No. Chans
MW1	2100 - 2950 $\text{cm}^{-1}$	1.0 $\text{cm}^{-1}$	787
MW2	1150 - 1650 $\text{cm}^{-1}$	0.5 $\text{cm}^{-1}$	1000
LW1	880 - 1150 $\text{cm}^{-1}$	0.5 $\text{cm}^{-1}$	637
LW2	650 - 880 $\text{cm}^{-1}$	0.4 $\text{cm}^{-1}$	672



# Questions for Users of AIRS Data

## ■ Climate

- What is the metric for climate model improvement? (.e.g. Weather uses correlation index)
- Do the climate model parameters and AIRS products represent the same physical state?
- What data sets are most important?

## ■ Weather

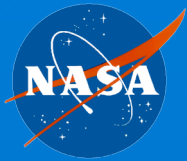
- What is AIRS impact on the regional forecast?

## ■ Science

- As AIRS surface products improve, what new science is possible?
- What is the significance of your finding to the average person? (For EPO)

## ■ Applications

- What can be done using AIRS data for applications?
  - E.g. airline industry, EPA, etc.



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### International Partners

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U of Bologna

Calheiros, R. (Continuing)

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McNally, T.

ECMWF

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## Summary

- AIRS Products Very Useful
  - Improving Weather Forecasts
  - Improving Climate Modeling
    - AIRS Is a Climate Quality Sensor
- Version 5 Complete
  - Improved Temperature Profiles
  - Improved Error Estimation
  - New Products: CO, CH<sub>4</sub>, SO<sub>2</sub> and Aerosol Indicators
  - Extended Product Testing and Verification
  - Validation Underway
- Version 6 Planning Underway. Meeting Wednesday Evening at 6:00 PM
- AIRS Paving the Way for Future Sounders